

Gaia Science Alerts

Łukasz Wyrzykowski

(pron. woocash vizhikovski)

with

**Simon Hodgkin, Ross Burgon,
Gerry Gilmore, Nick Walton,
Vasily Belokurov, Wyn Evans**

Institute of Astronomy, University of Cambridge, UK
email: wyrzykow@ast.cam.ac.uk



04 December 2009

Science Alerts

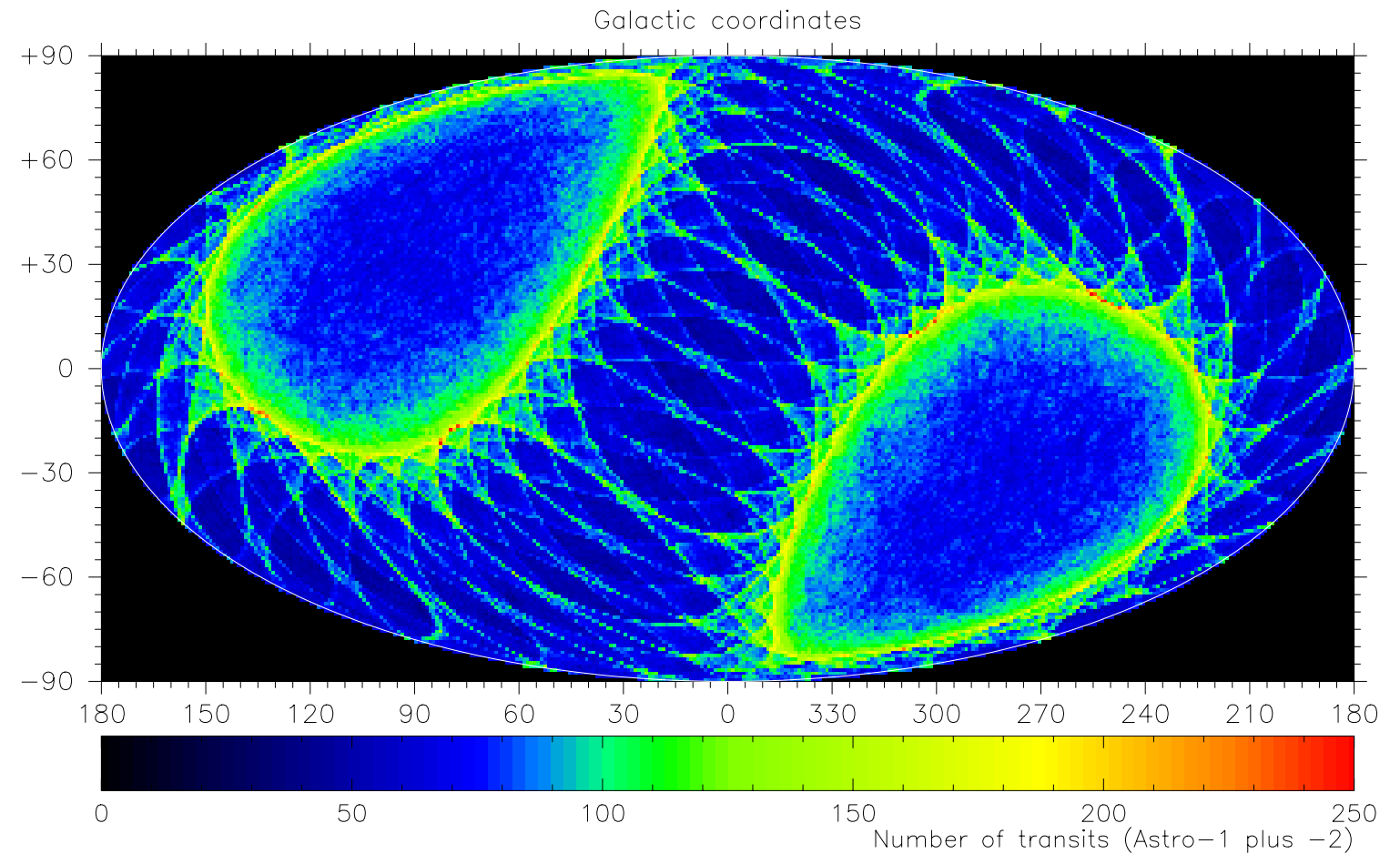
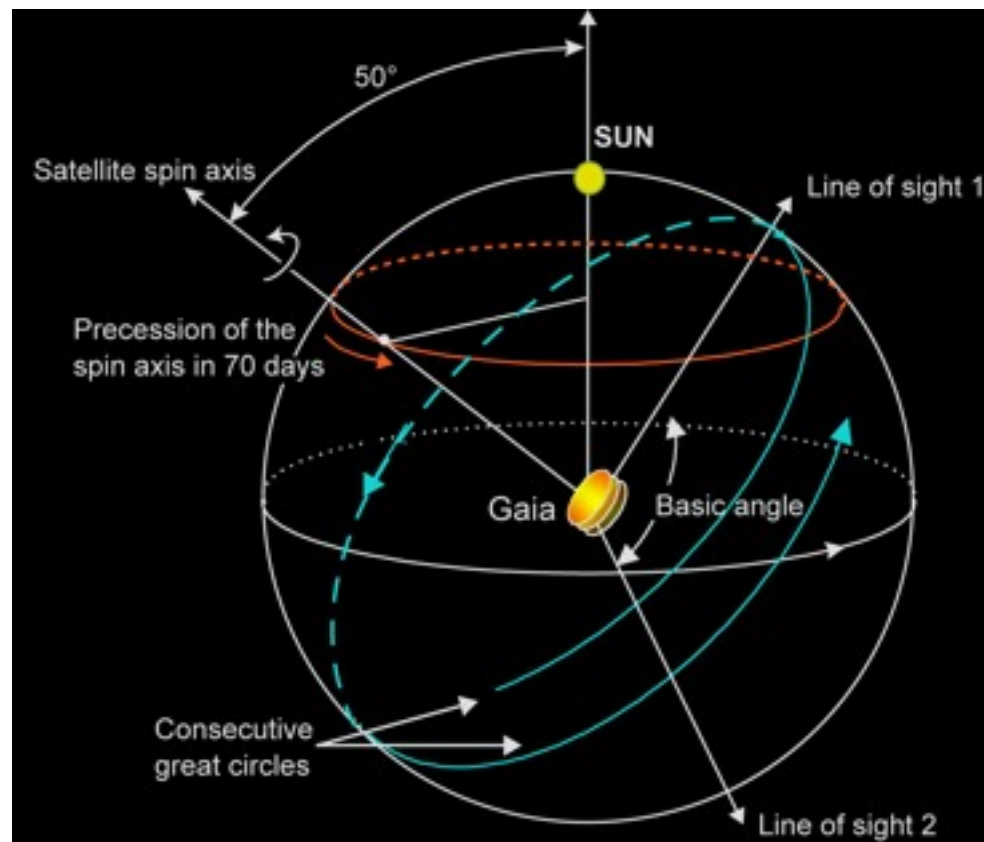
aims:

- detect unexpected and rapid changes in the flux
- or appearance of new objects
- trigger ground-based follow-up
- provide targets to the community to be studied at peculiar states

methods:

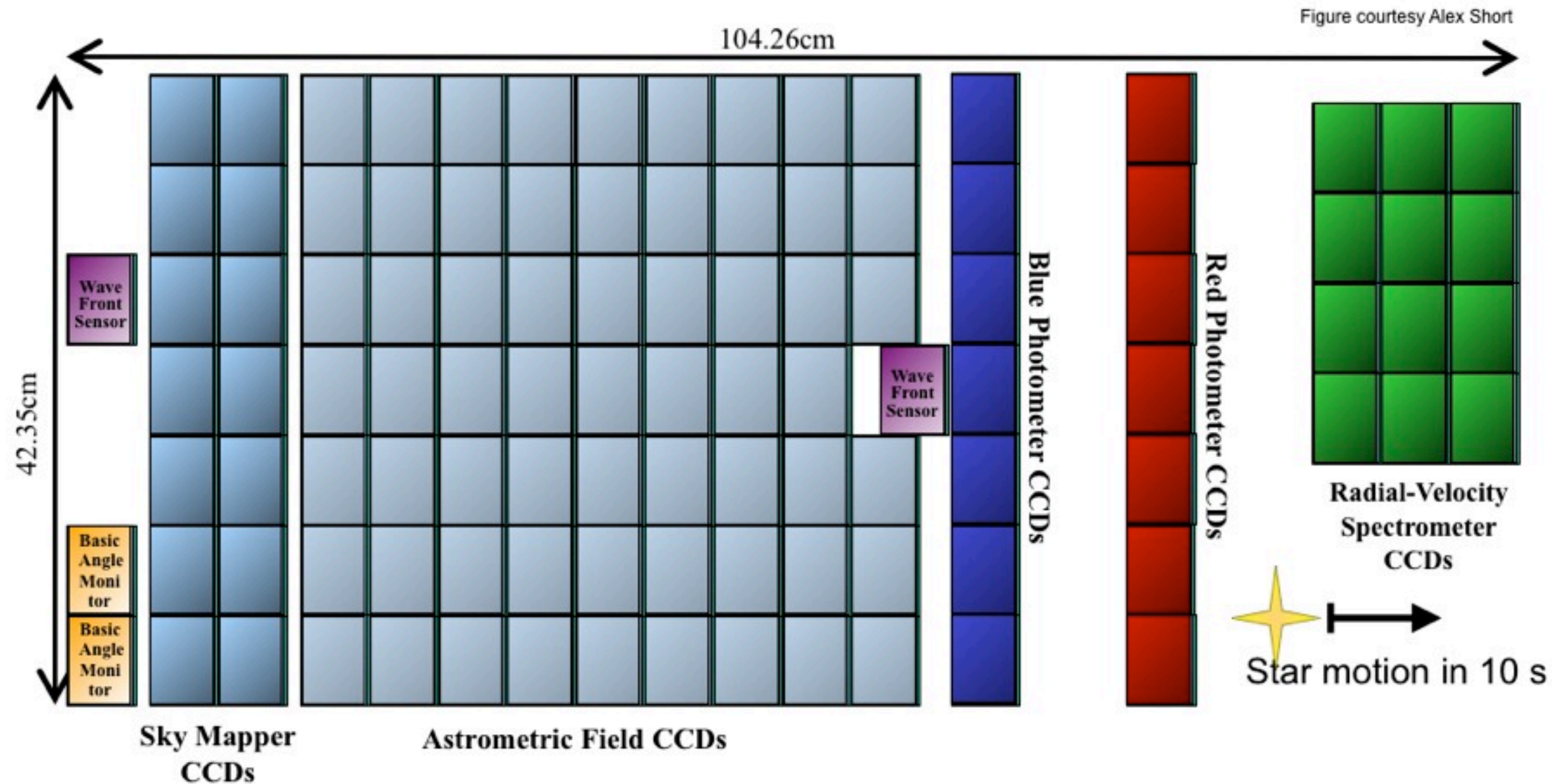
- run in near-real-time: between couple of hours and 24h after observation
- use photometric data, calibrated roughly
- release of an alert through VO

Scanning law



- Two telescopes - time between subsequent FOVs: **106.5m**
- Time between successive scans: **6 h**
- Field revisited every **~70 days**
- Each object measured **~80** times (200 at the nodes)

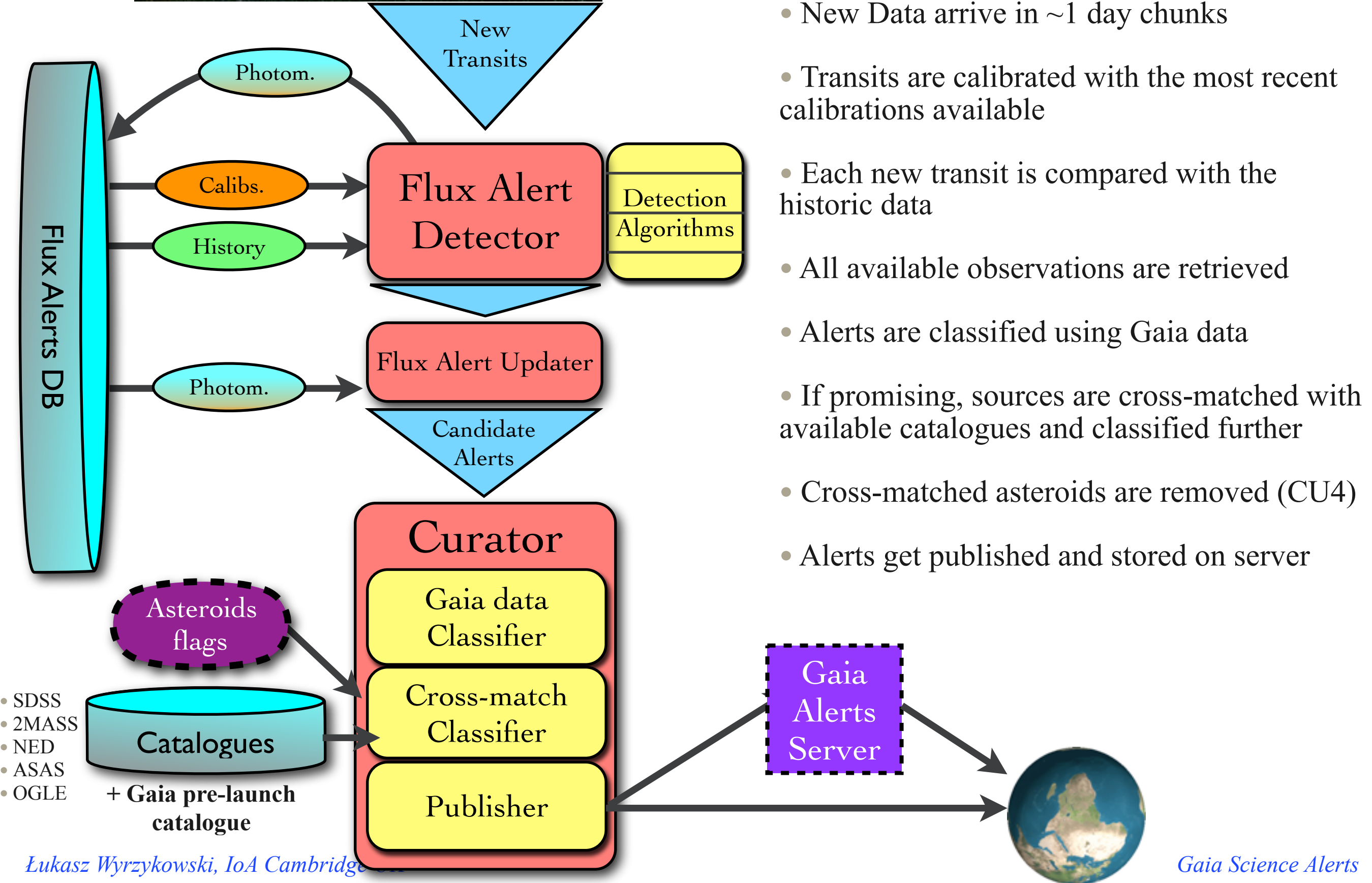
Gaia's Focal Plane



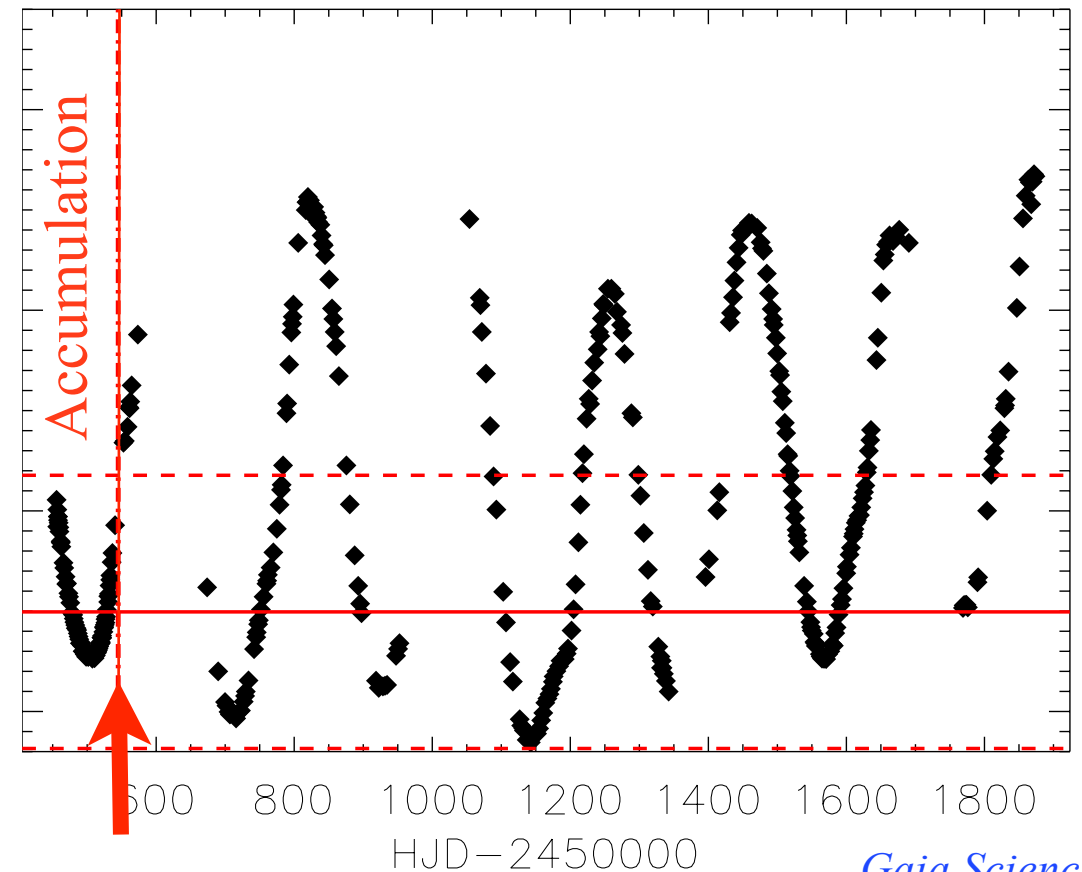
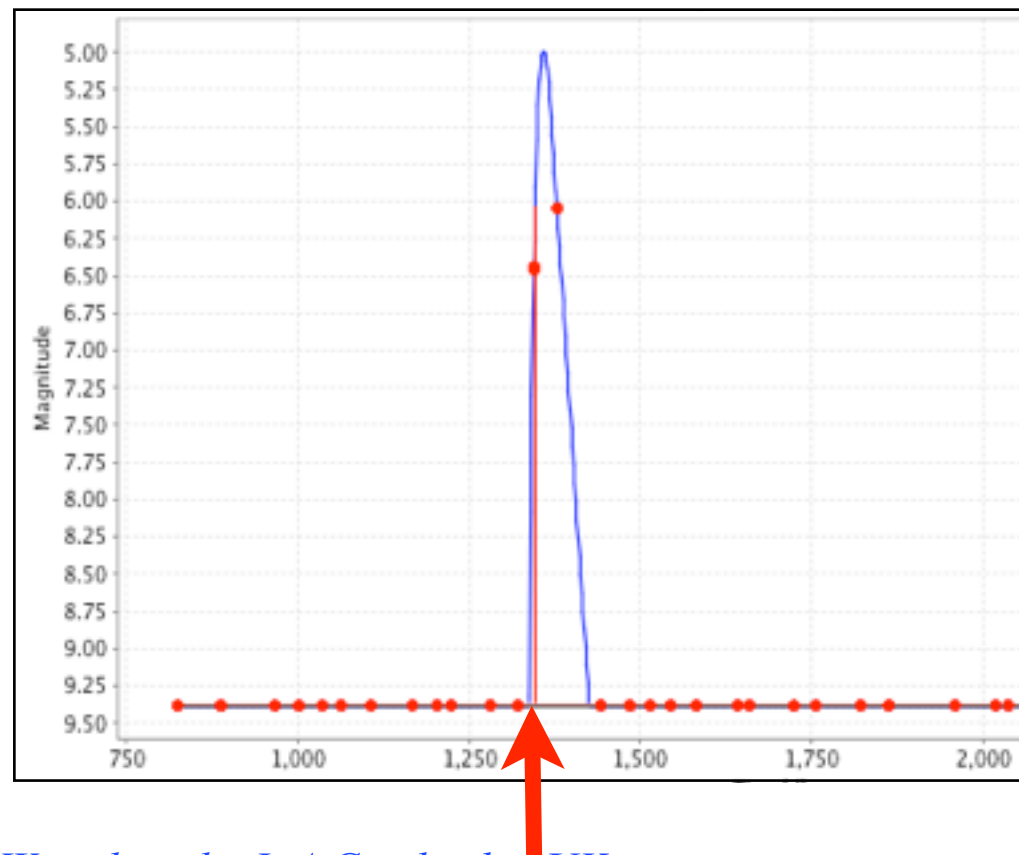
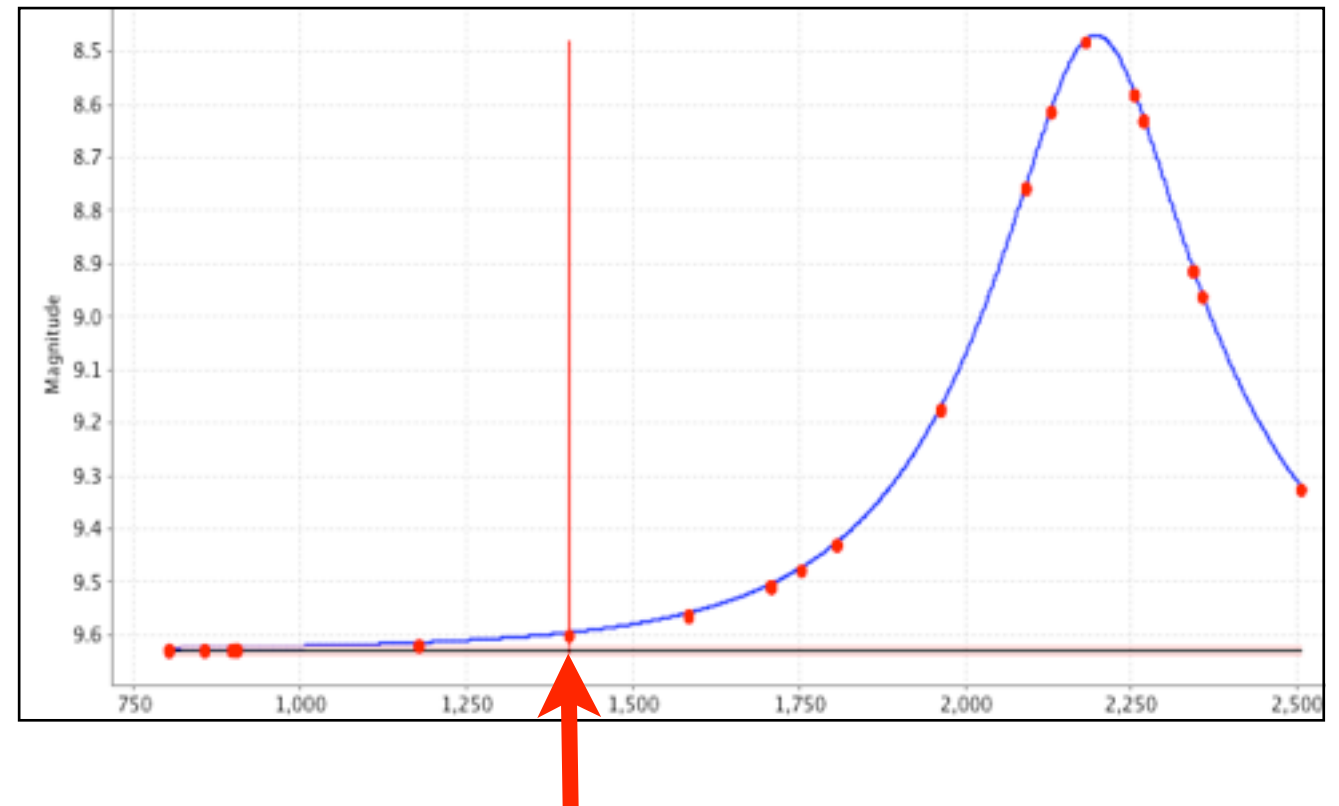
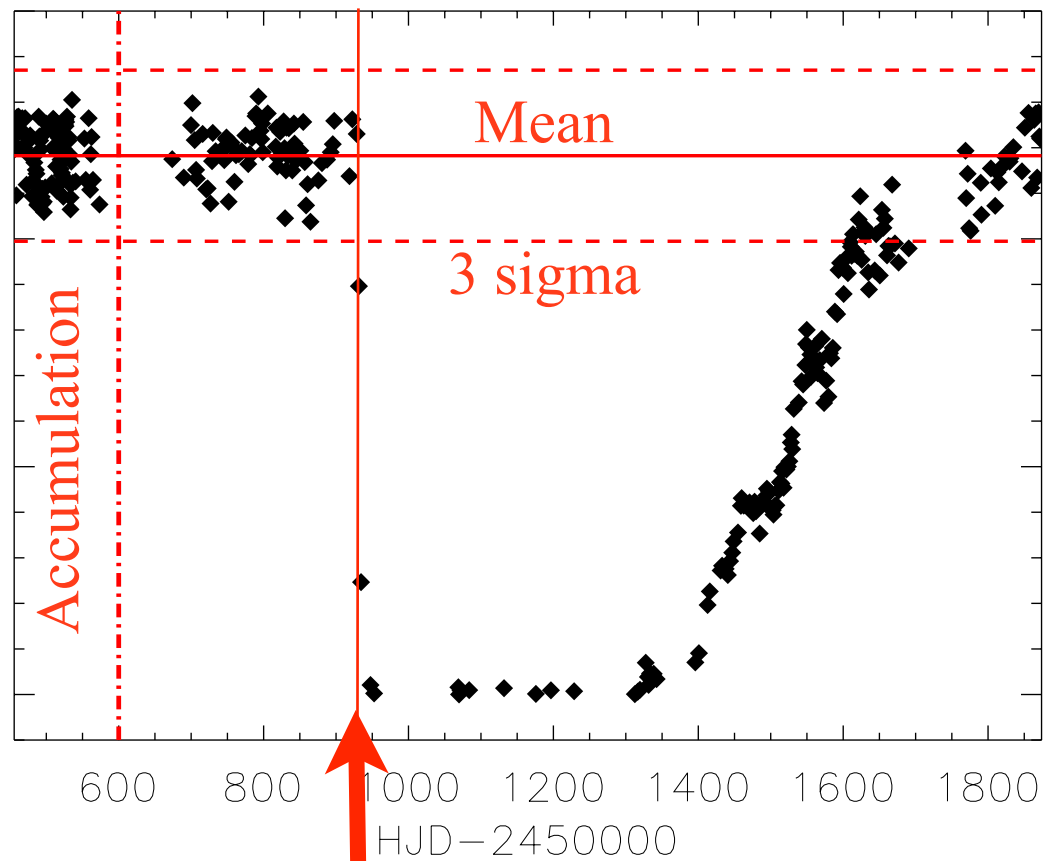
- Chip transit: 4.4s
- Field transit (9 astrometric CCDs): 40s



Operation scheme

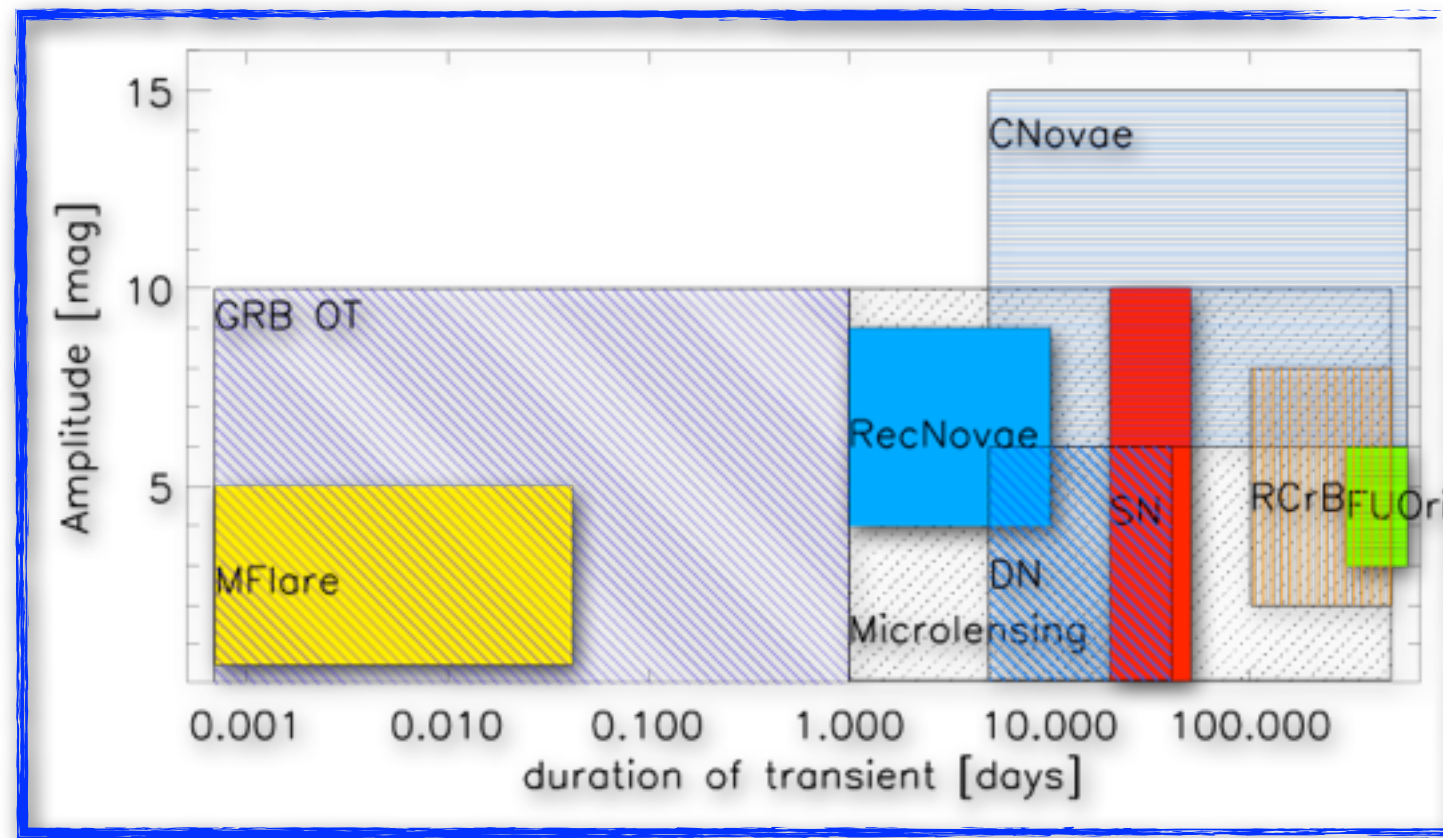
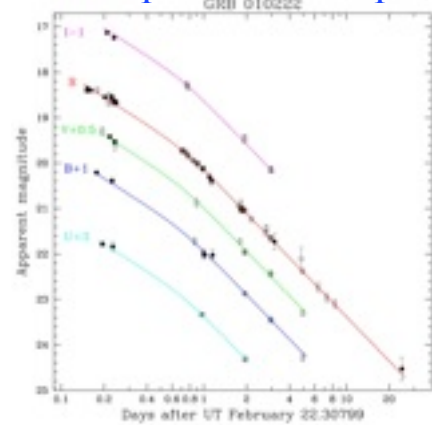


How detection works?

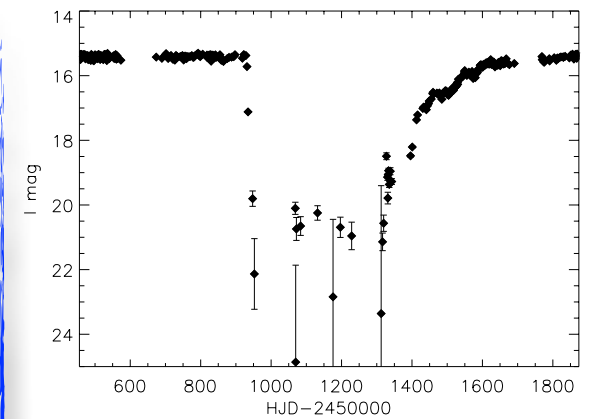


Potential Triggers

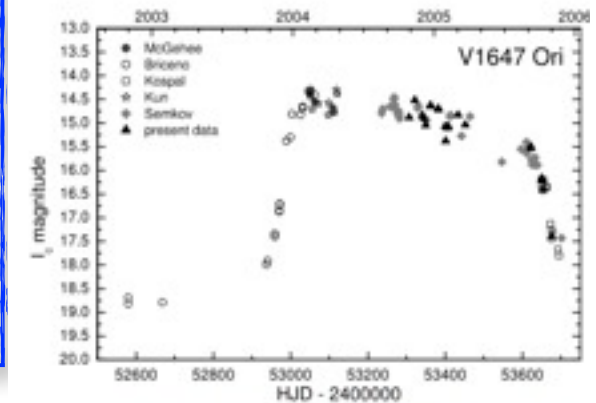
GRBs optical counterparts



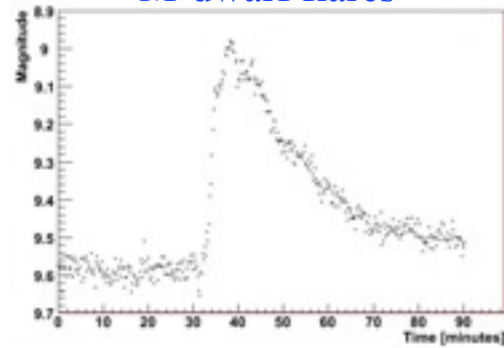
R Coronae Borealis



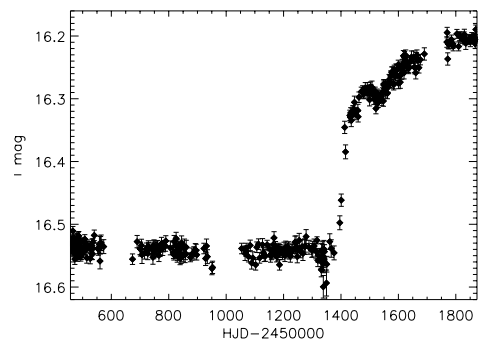
FU Orionis and similar



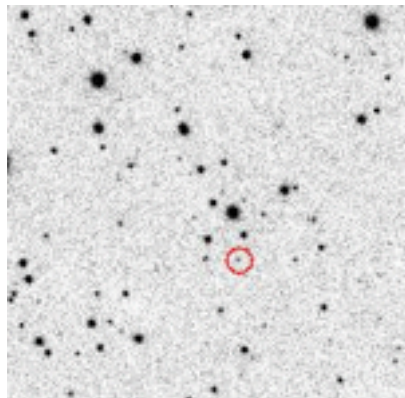
M-dwarf flares



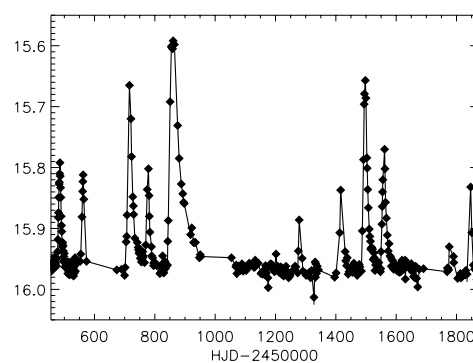
Be stars



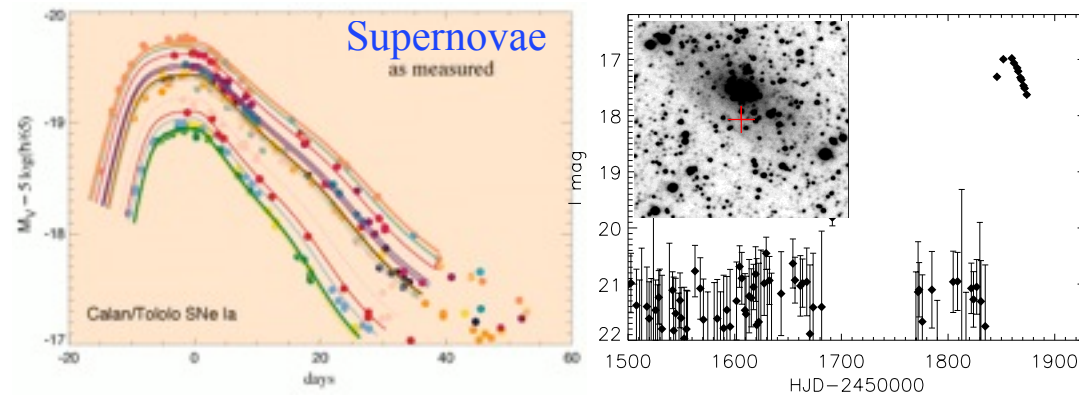
Asteroids



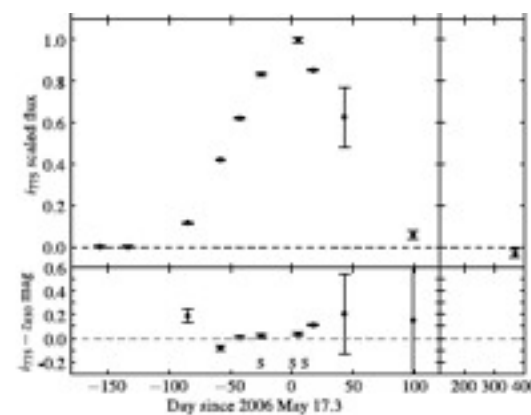
Dwarf novae



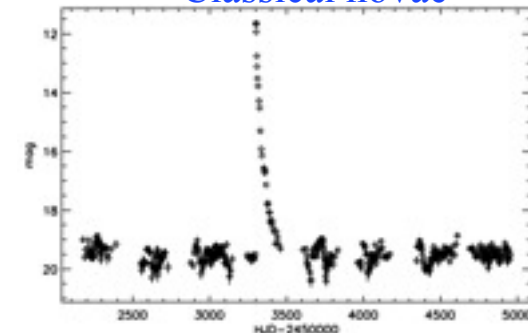
Supernovae



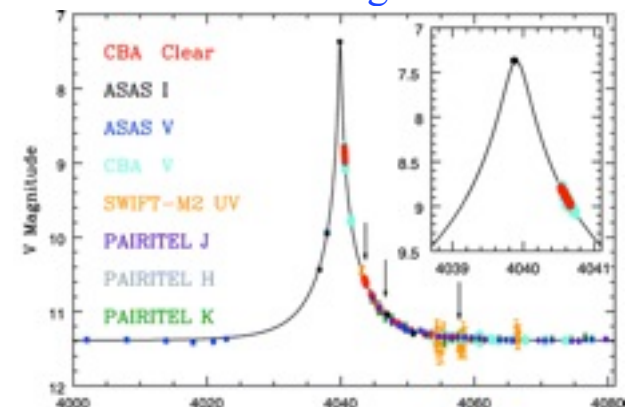
NEW THINGS??



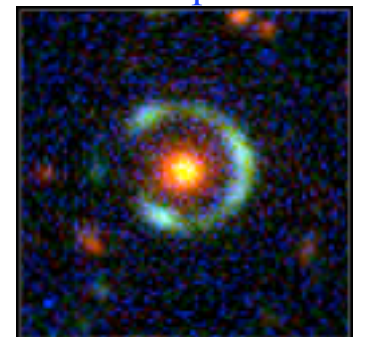
Classical novae



Microlensing events



Lensed supernovae



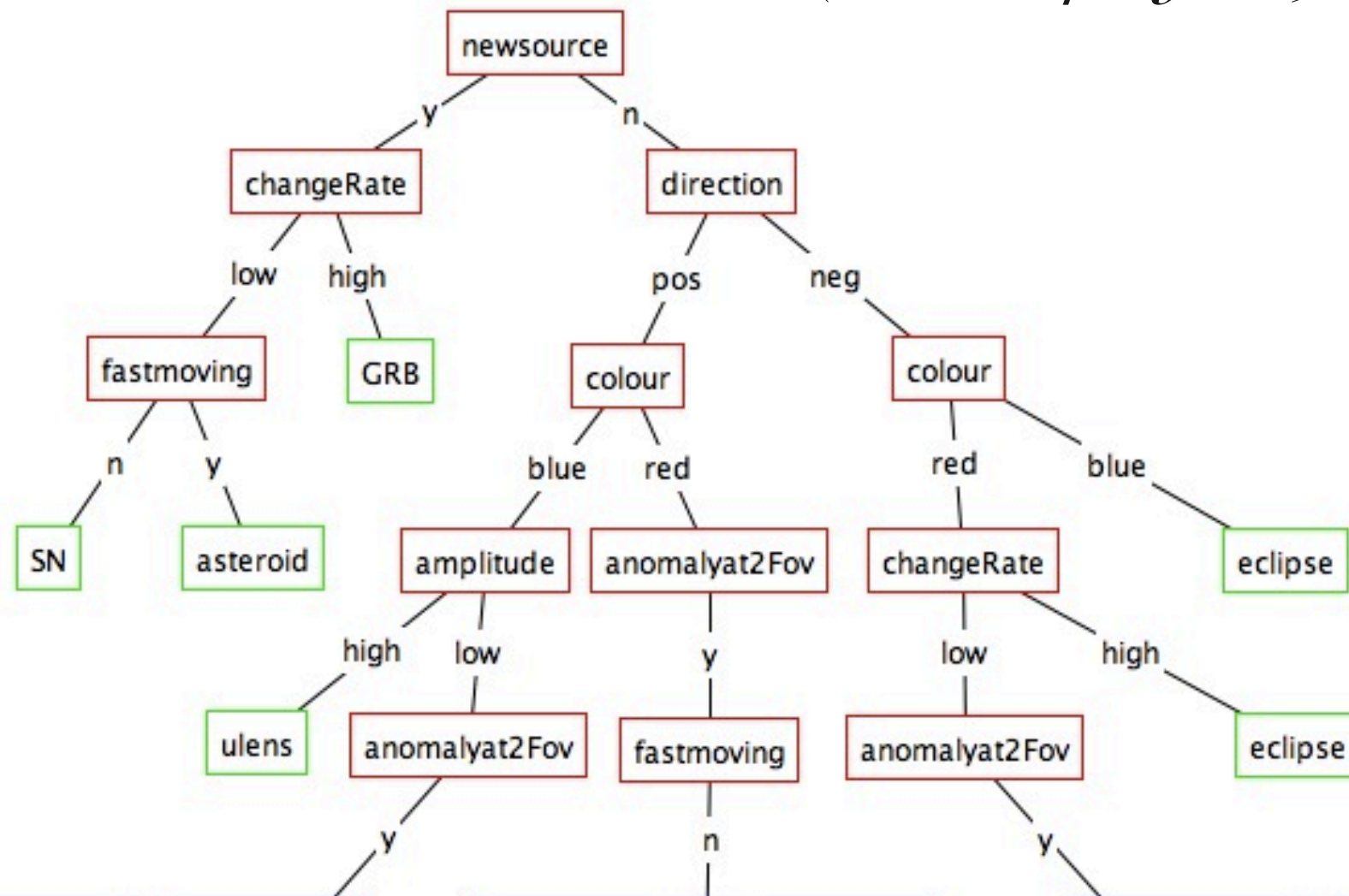
Gaia Classification - data used

(work in progress)

- G-band photometry (light curve)
- BP/RP colour
- BP and RP spectra (raw)
- morphology of the source from LSF fit (galaxy/star)
- source motion flags (fast asteroid?)
- Gaia catalogues (later in the mission)
 - galaxies (CU4)
 - variable stars classified into types (CU7)
 - astrophysical parameters, e.g. T_{eff} , spectral type (CU8)
 - preliminary astrometry (CU3)

Gaia Classification - Decision Trees

(work in progress)



exemplary parameters:

- is the anomaly visible on **two subsequent FoVs**?
- preliminary Gaia **colour**
- is the source **new** to Gaia?
- **amplitude** of variation

Leaf				
Value	Count	Probability		
SN	0	0.0		
GRB	0	0.0		
Be	1	0.5	■	
ulens	1	0.5	■	
RCrB	0	0.0		
RCrB-up	0	0.0		
asteroid	0	0.0		
eclipse	0	0.0		

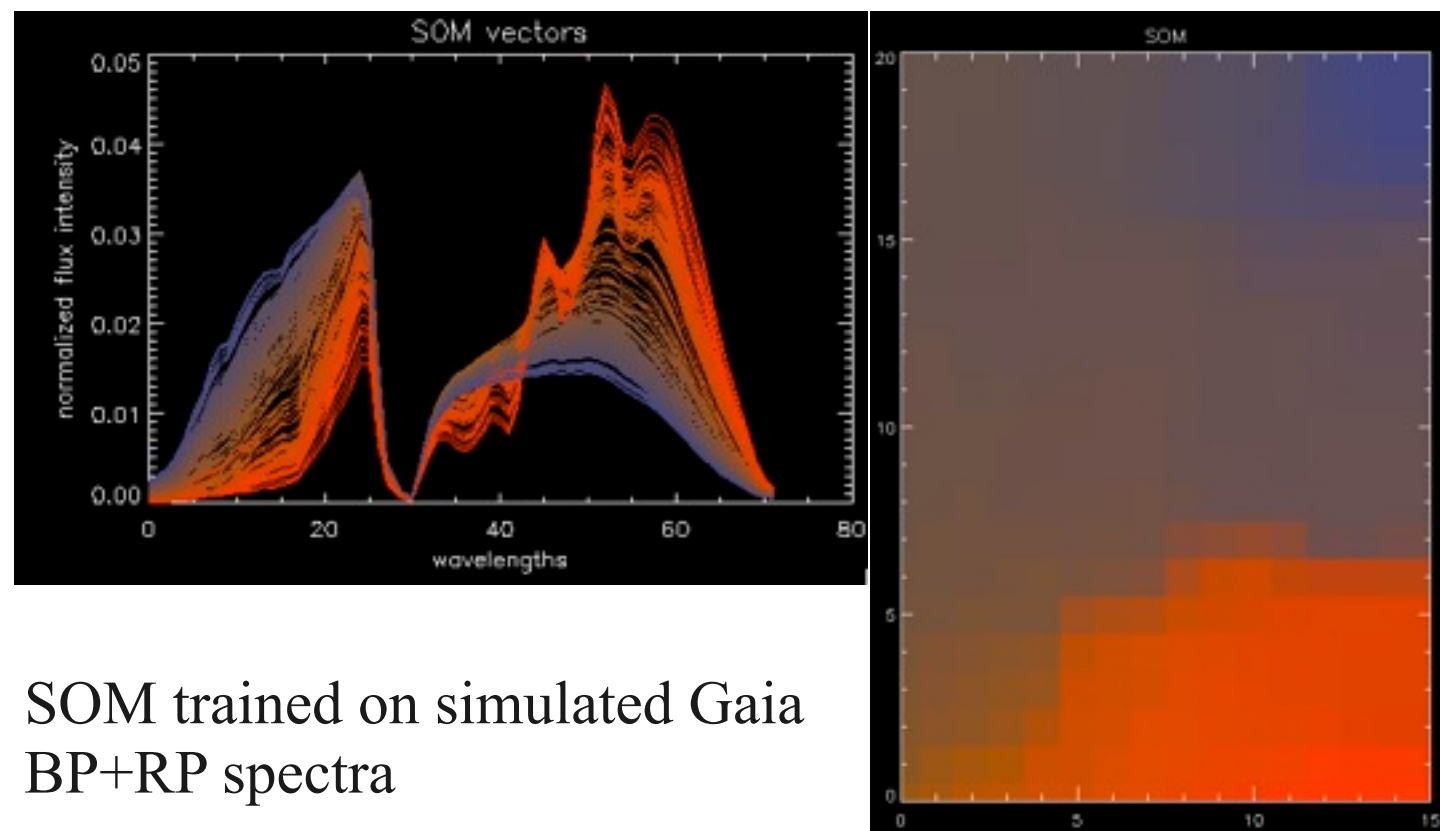
Leaf				
Value	Count	Probability		
SN	0	0.0		
GRB	0	0.0		
Be	0	0.0		
ulens	2	0.5	■	
RCrB	0	0.0		
RCrB-up	2	0.5	■	
asteroid	0	0.0		
eclipse	0	0.0		

Leaf				
Value	Count	Probability		
SN	0	0.0		
GRB	0	0.0		
Be	0	0.0		
ulens	0	0.0		
RCrB	2	0.5	■	
RCrB-up	0	0.0		
asteroid	0	0.0		
eclipse	2	0.5	■	

Gaia Classification

- employing raw BP/RP spectra
(work in progress)

- raw, low dispersion spectra will be available along with the photometry
- extracting spectral type of the source helps a lot in alerts' classification
e.g. false-alarm: large amplitude faint Mira
- some sort of basic classification can be done with Self-Organizing Maps



SOM trained on simulated Gaia
BP+RP spectra

Cross-matching

(work in progress)

*uses existing catalogues available through Virtual Observatory,
Astrogrid or local copies, e.g. SDSS, 2MASS, NED, ASAS, OGLE*

The following information will be employed:

- star, source close to galaxy or orphan new source?
- magnitudes and colours in optical and IR
- X-ray source, gamma source?
- time-domain photometry
- variability classification (*e.g.* recurrent nova, eclipsing)
- anomalies alerted by other surveys (*e.g.* GRBs alerts)
- asteroids from CU4

Rates of alerts (preliminary)

<i>alerting object</i>	<i>5-yrs (Entire Mission)</i>	<i>3 months (Verification Phase)</i>	<i>main location</i>
Supernovae <19 mag	6000	300	out of plane
Microlensing (all sky)	750	37	out of plane
GRB optical counterparts	~1500 (?)	1-2 (?)	out of plane
AGNs	500,000 (?)	thousands (?)	out of plane
Asteroids	thousands (?)	hundreds (?)	out of plane
Microlensing (bulge)	3000	150	bulge/plane
CN	150	7	gal. plane
R CrB-type stars	hundreds(?) / 60	1 (?) (new)	gal. plane
FU Ori	14	none (?)	gal. plane
Eclipsing binaries	a million (?)	thousands (?)	gal. plane
M-dwarf flares	2000	2000	gal. plane
Long period variables/Miras	thousands (?)	hundreds (?)	gal. plane
Be stars	thousands (?)	hundreds (?)	gal. plane
DN (U Gem)	500	100 (?)	gal. plane

interesting
out of galactic plane

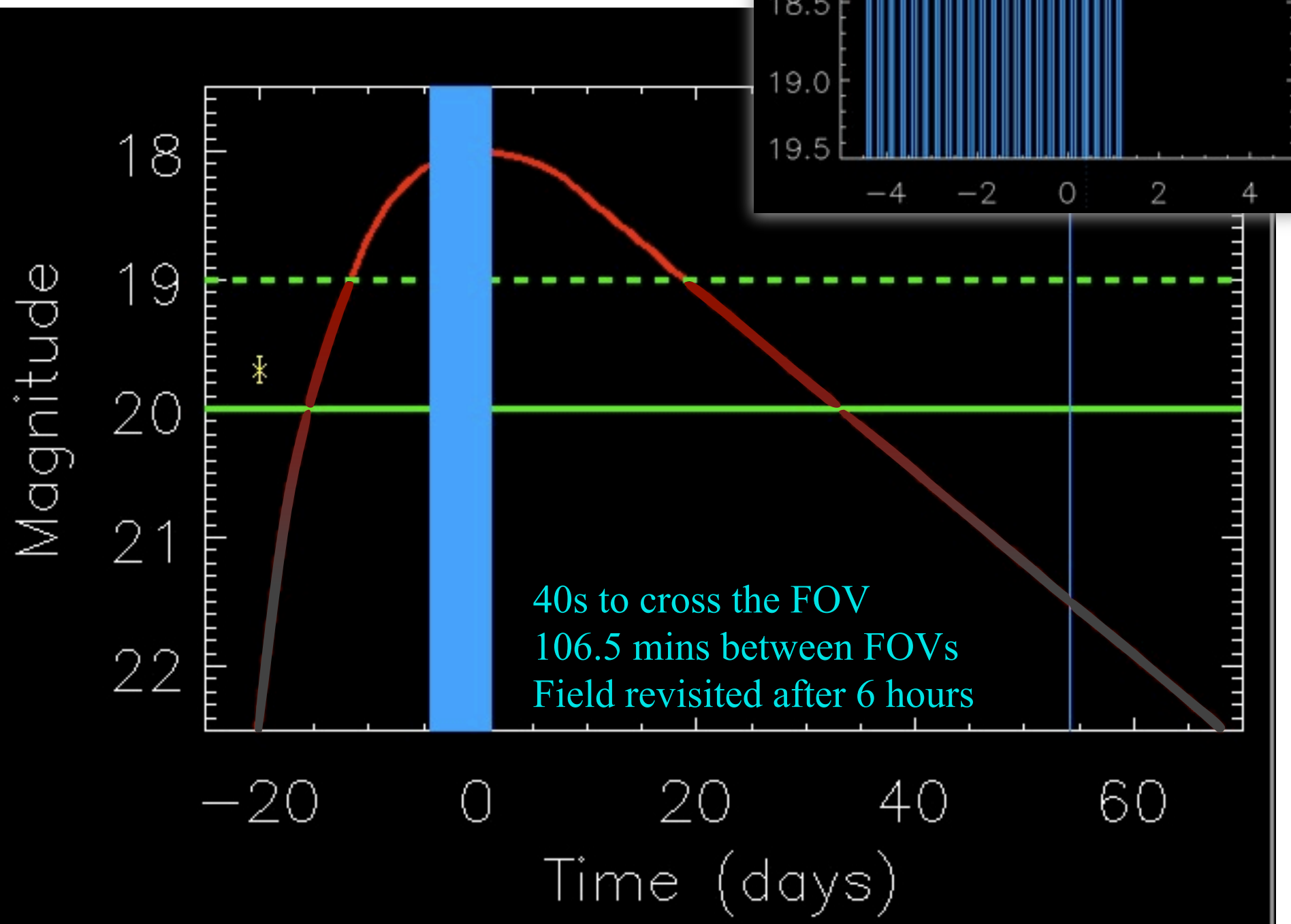
contaminant,
out of galactic plane

interesting
in the galactic plane

contaminant,
in the galactic plane

Supernovae

- 6000 SNe to G=19
- Around 1/3 before maximum

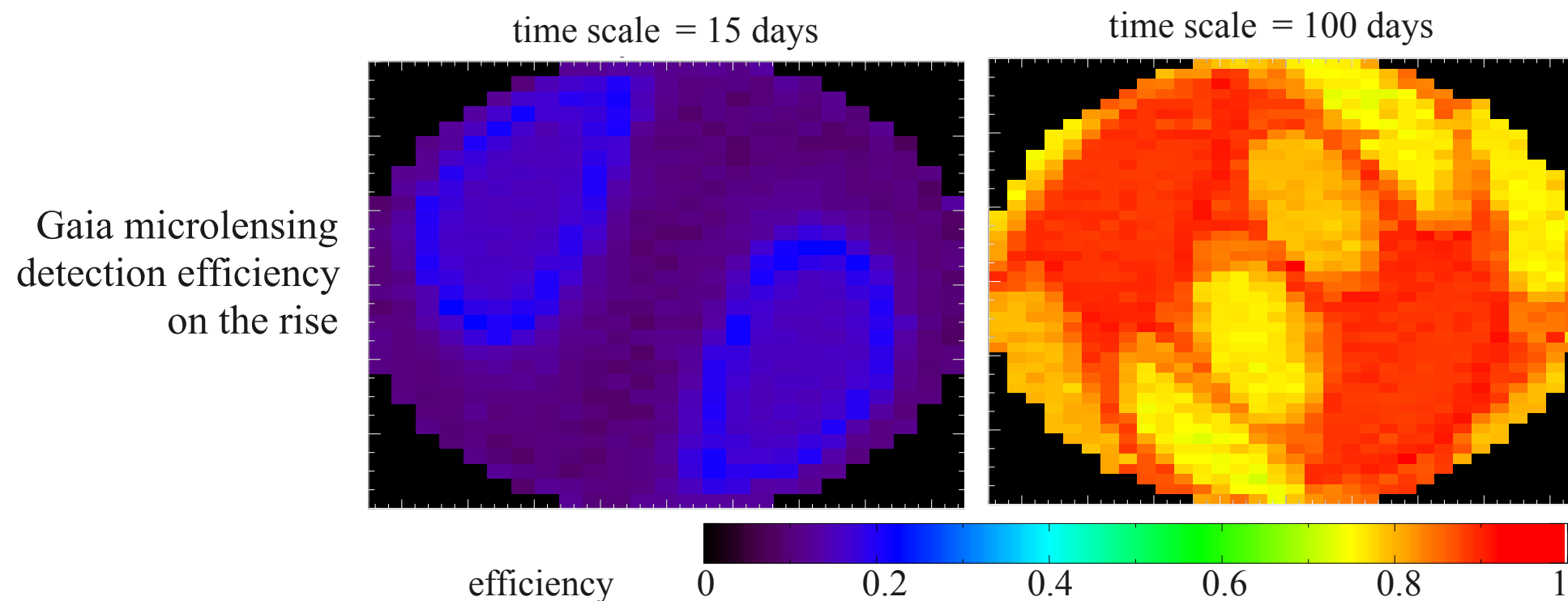


- Successive transits will measure consistency and slope.

- Host galaxy contribution determines whether source is new to Gaia.

Microlensing Events

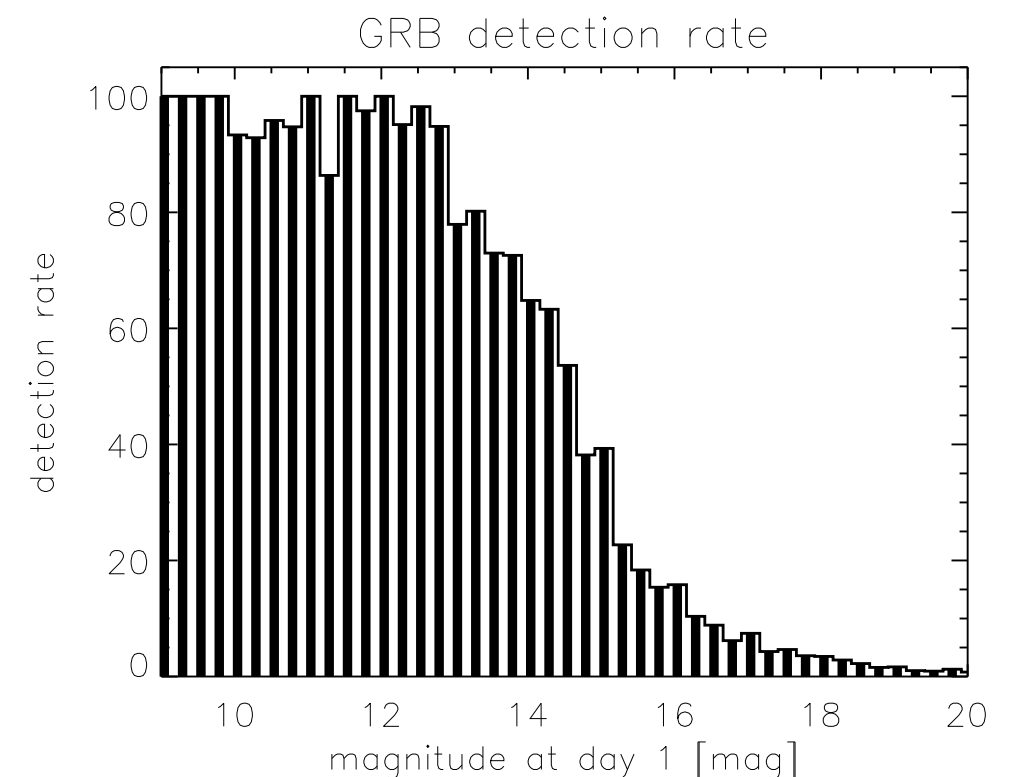
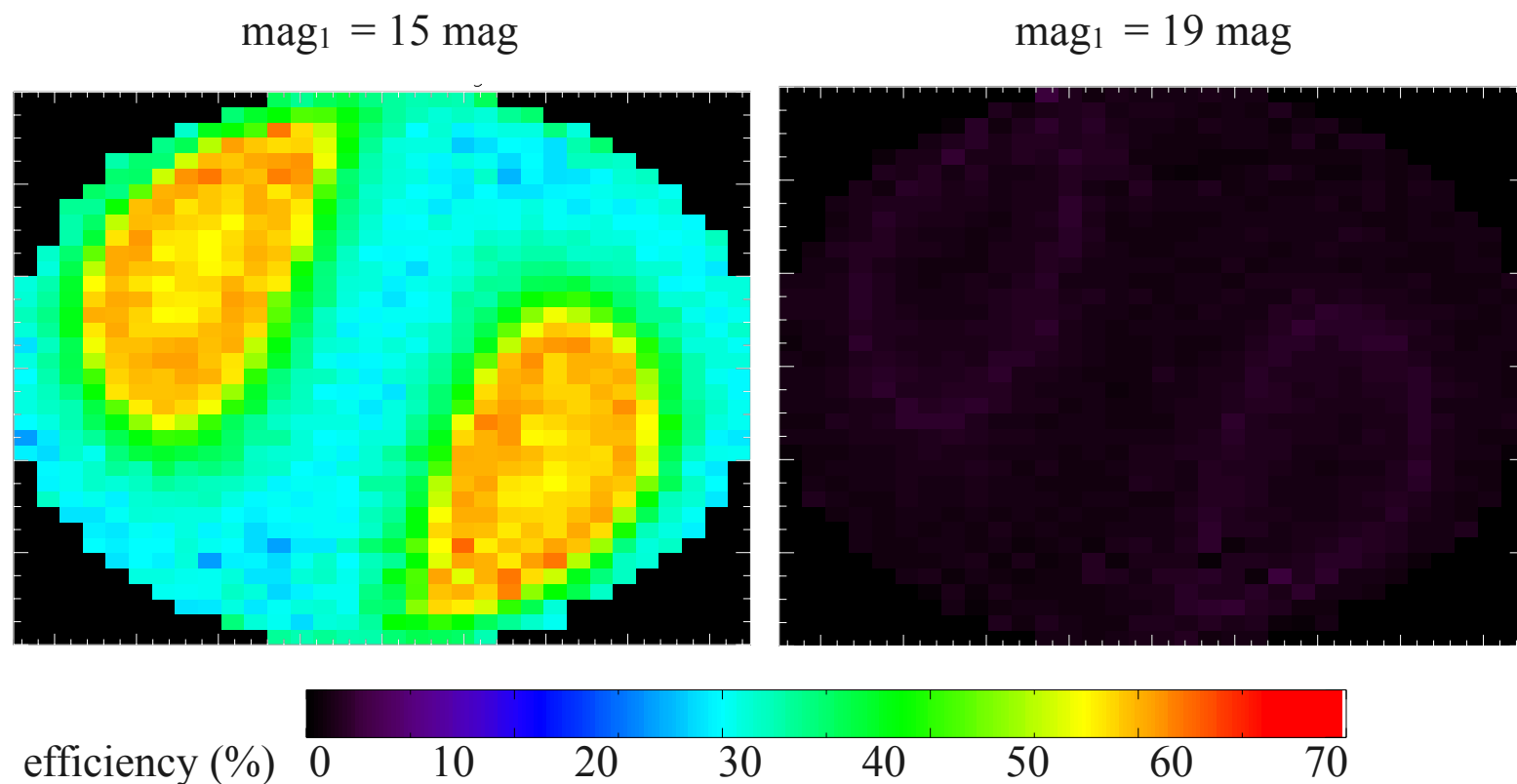
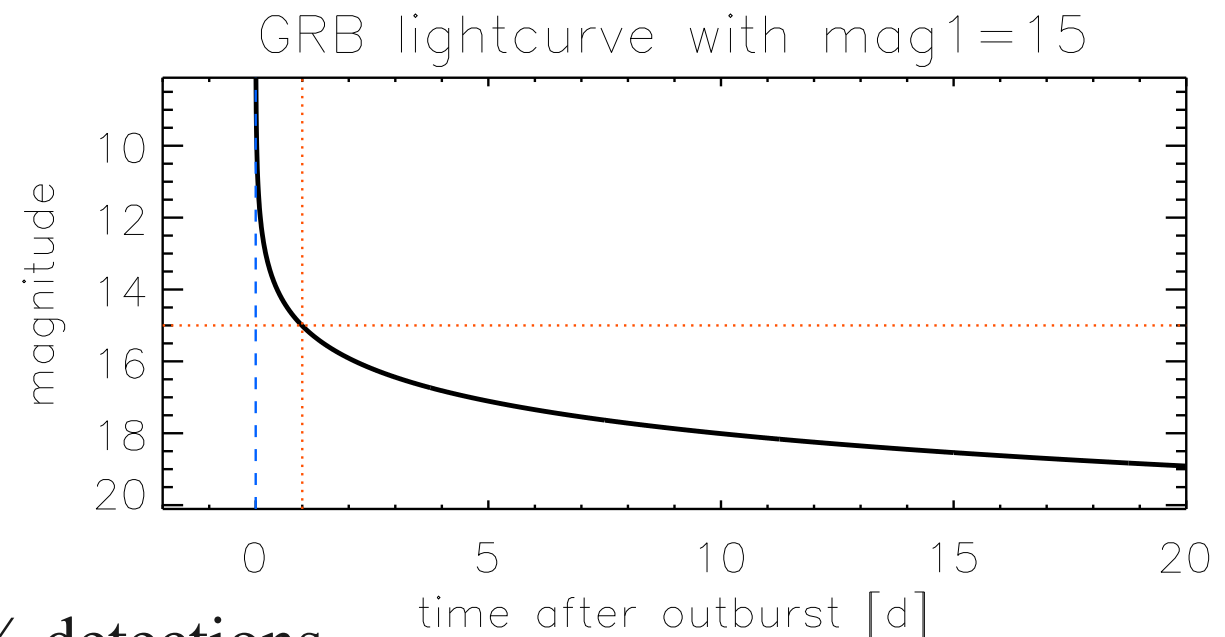
- **>3000** events expected to occur towards the bulge, but many lost due to **crowding** (situation is better in Baade's Window)
- **~ 700** events expected over all sky
- photometric alerts on **1000+** events
- **~100%** long events detected - the most interesting ones (nearby or massive lens)



- **25,000** astrometric events expected
- mainly those with nearby lens detectable (see Belokurov&Evans 2002)

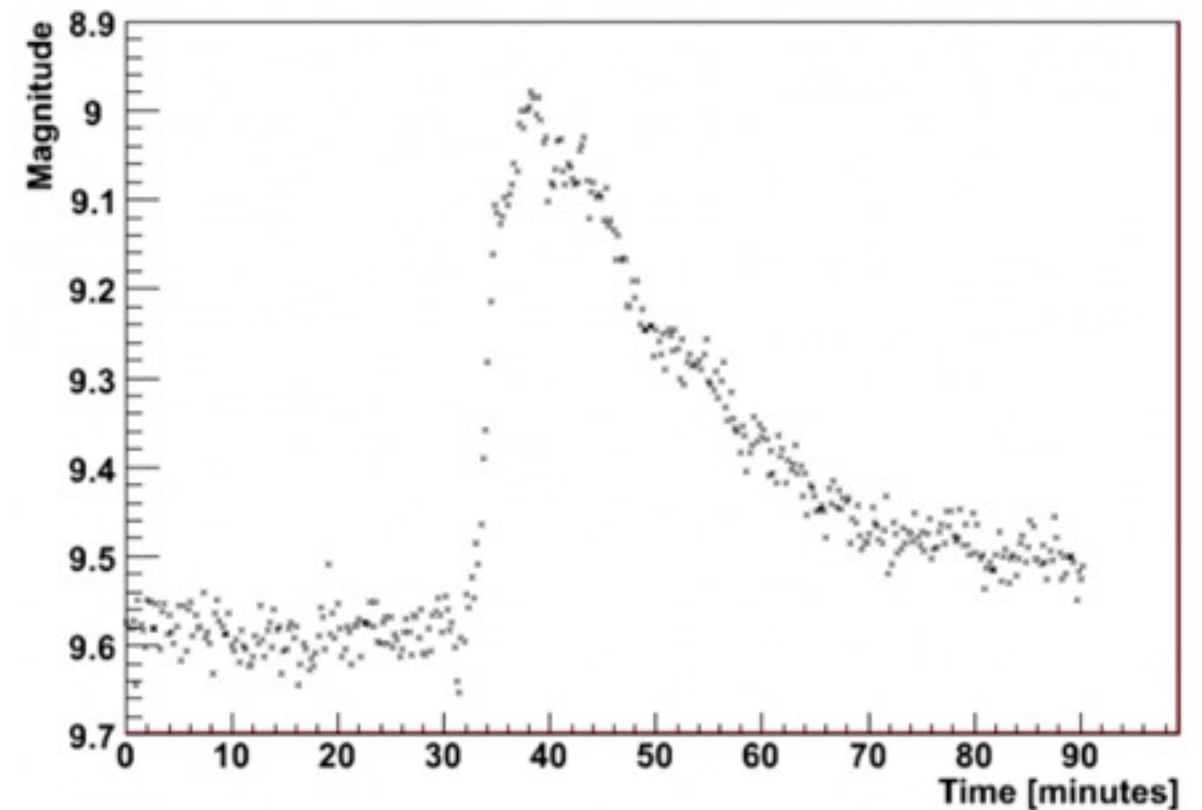
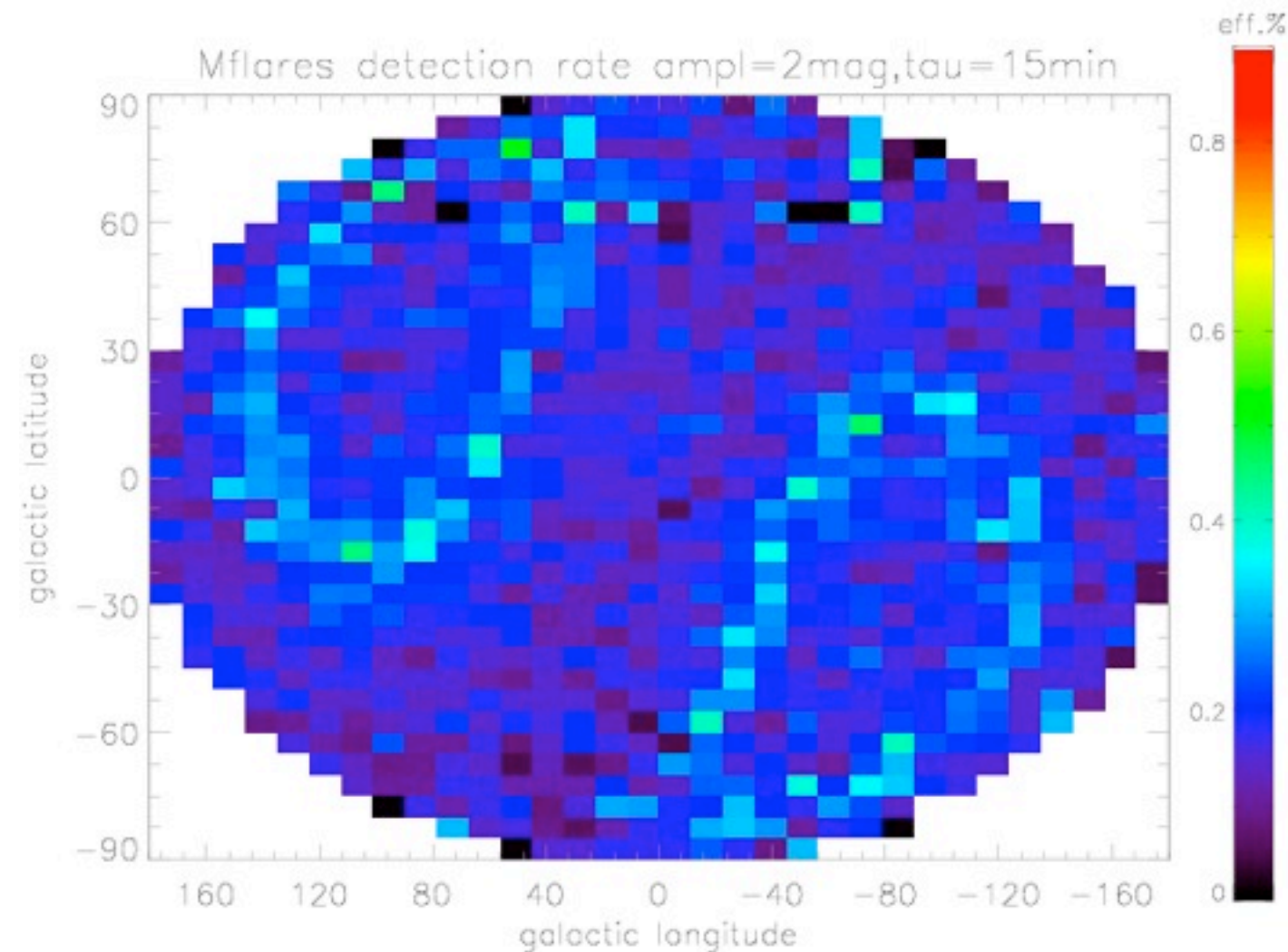
Gamma-ray bursts afterglows

- 300 per year detected
- time-scales from seconds to days
- most GRBs with $\text{mag}_1=19$ mag ($\sim 5\%$ detectability)
- GRBs with $\text{mag}_1=15$ mag have 30-60%
- extremely bright (rare) are usually longer: 100% detections



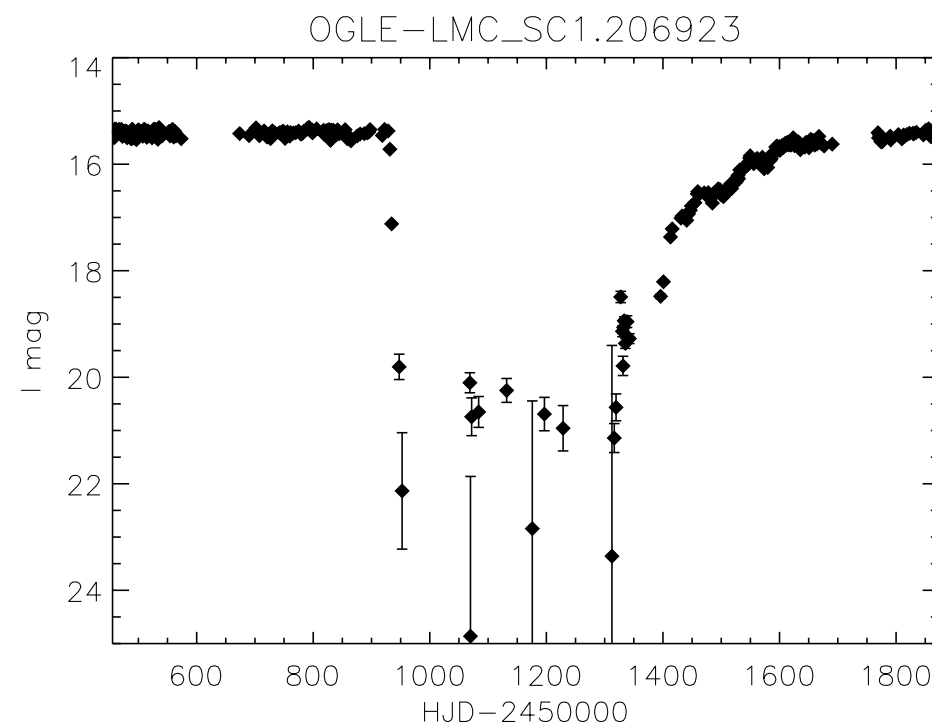
M-dwarf flares

- time-scales from seconds to minutes
- amplitudes up to 5 mag
- not very interesting for immediate follow-up
- very low detection rate (0.4 %)



R CrB-type stars

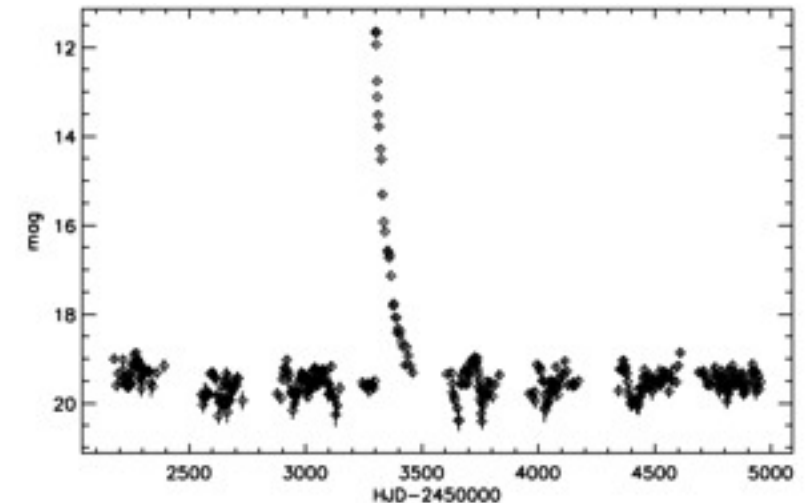
- very few known (~ 50), but ~ 3000 expected
- can drop up to **8 mag** in brightness over a week!
- mechanism of these dimmings remains unknown
- most found in the **Bulge** and **MCs** by microlensing surveys
- **ASAS** (all sky) provided some new findings, limited by 14mag
- Science Alerts will easily find new much fainter RCrB
- spectroscopic follow-up during the event can help solving their mystery



Other interesting triggers

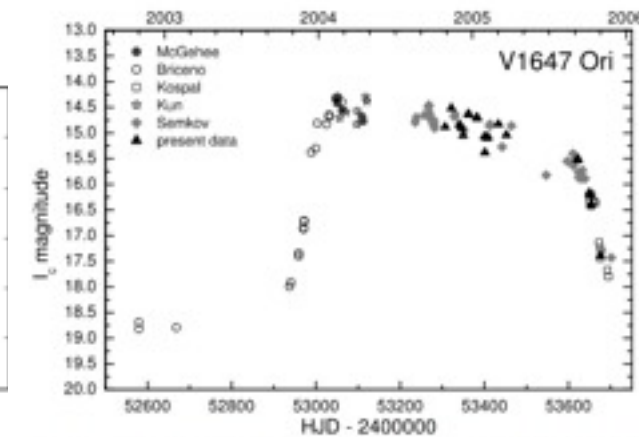
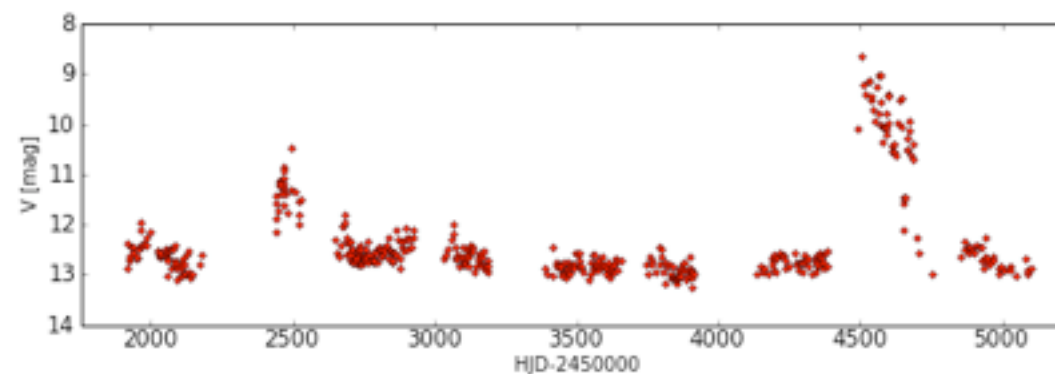
◆ Classical and recurrent novae

- potential distance indicators
- can be detected in MW and other galaxies
- large amplitudes, wide range of time-scales



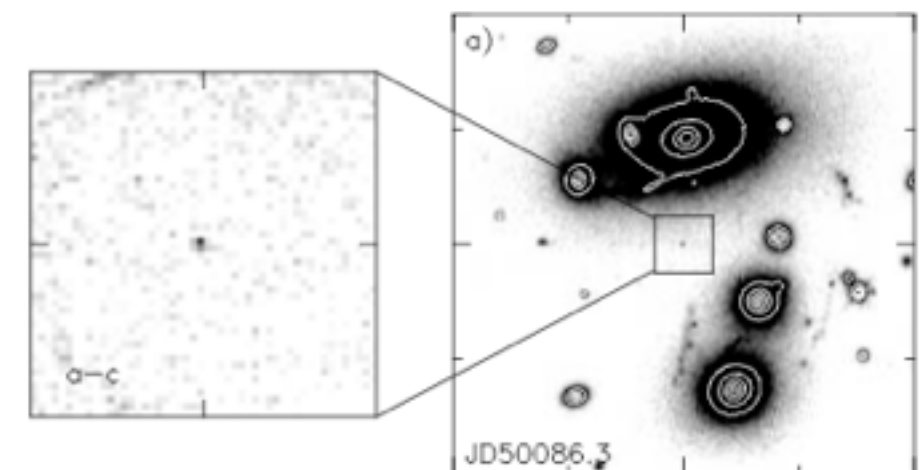
◆ FU Orionis/EX Lupi

- unstable pre-MS stars
- rare class (few known)
- several magnitudes up
- X-ray variability
- long time-scales
- FU Ori repeats every ~40 years!



◆ Gravitationally lensed distant supernovae

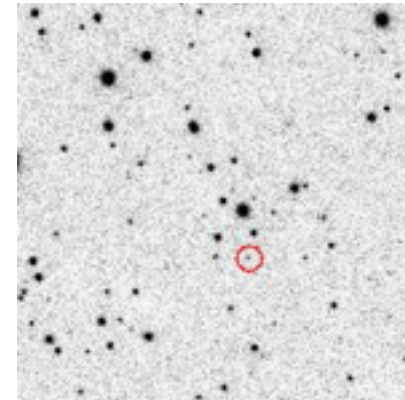
- unique uniform all-sky monitoring
- high redshift SNe rates, distances, H₀



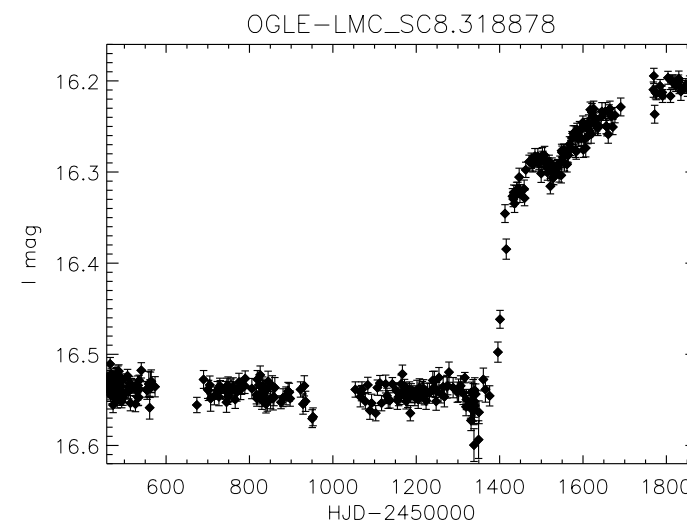
Common and not interesting(?)

➔ **Asteroids** - loads!

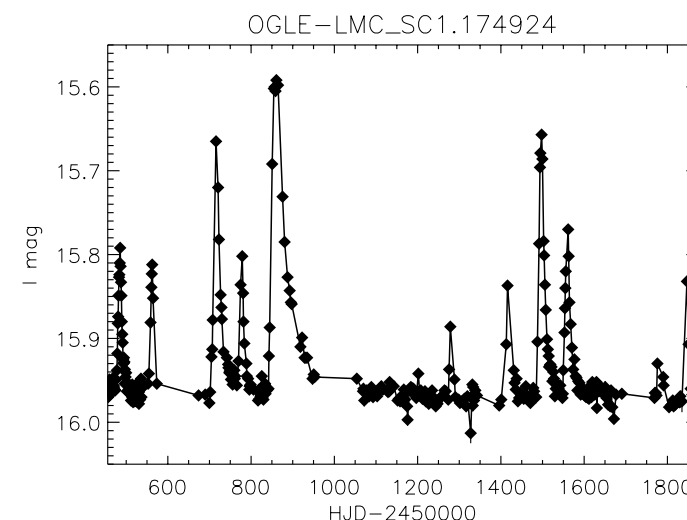
- faster ones can be removed after second FOV transit



➔ **Be stars** - low amplitudes, blue colours



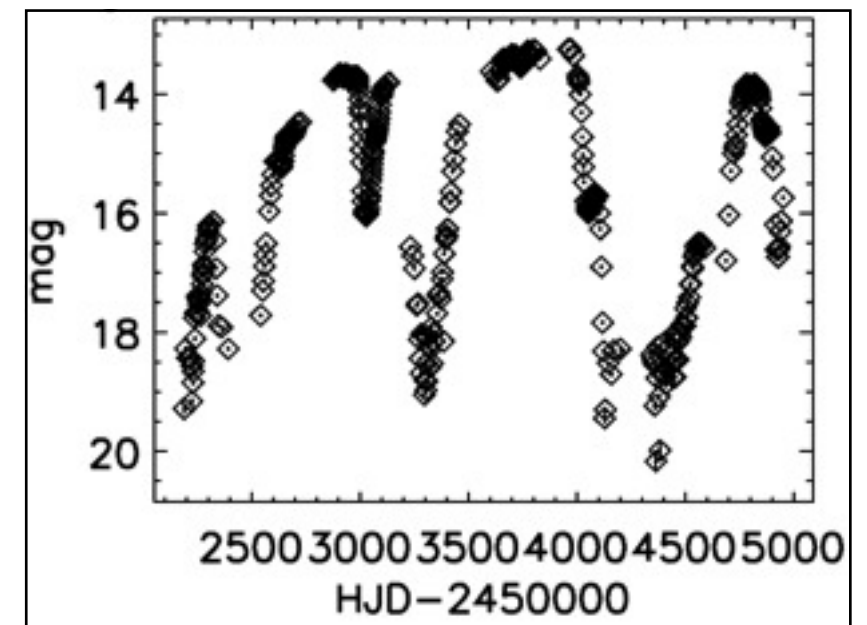
➔ **Dwarf Novae** - low amplitudes, repeating



➔ and many more...

Monitoring System (Watch List)

- ▶ we can also monitor known anomalous objects within Science Alerts
- ▶ easily coded - just add an object to the list of alerts
- ▶ many of the things we alert on will be subsequently monitored
- ▶ but some will not alert (highly variable?), but are known to be anomalous
- ▶ *for example:* known RCrB stars can be monitored in order to alert on a dimming event



Science Alerts verification - the proposal

- ◉ Science Alerts will be the **first Gaia data released** to the public
- ◉ Alerts should be as **reliable** as possible
- ◉ We need a training phase for our detection and classification methods using **ground-based follow-up** observations.
- ◉ It should take place **after 180d** (one cycle), when we have some history of all of the sky
- ◉ It could last **2-3 months**
- ◉ After, the alerts will be made public for follow-up

Science Alerts verification and follow-up - the requirements

- ◉ **immediate response** (ToO or dedicated telescopes)
- ◉ **north** and **south** hemispheres
- ◉ **>2m** telescopes would be ideal (smaller still good for brighter objects)
- ◉ **confirmation** of an anomaly with imaging
- ◉ high resolution deep **imaging** - e.g. host galaxy for a SN, or knots of PN
- ◉ high resolution **spectra** to classify an anomaly, e.g. carbon star for RCrB-type behaviour
- ◉ continuous **photometric follow-up** to learn more about an anomaly in order to classify it, e.g. eclipsing binary (detection of periodicity), microlensing (continuous rise and then fall)
- ◉ rule out **asteroids** - detect fast moving objects

Please contact Lukasz Wyrzykowski for password.

Main Page

Welcome to the web site of the Gaia Science Alerts Working Group!

The Science Alerts Working Group is focussed on the real-time detection of variable sources. These include supernovae, microlensing events, exploding and eruptive stars, etc.

FU Orionis (FUors)

FU Orionis (V1647 Ori) is young pre-main sequence stars, illuminating a McNeil's nebula in the vicinity of NGC 2068 star-forming region.

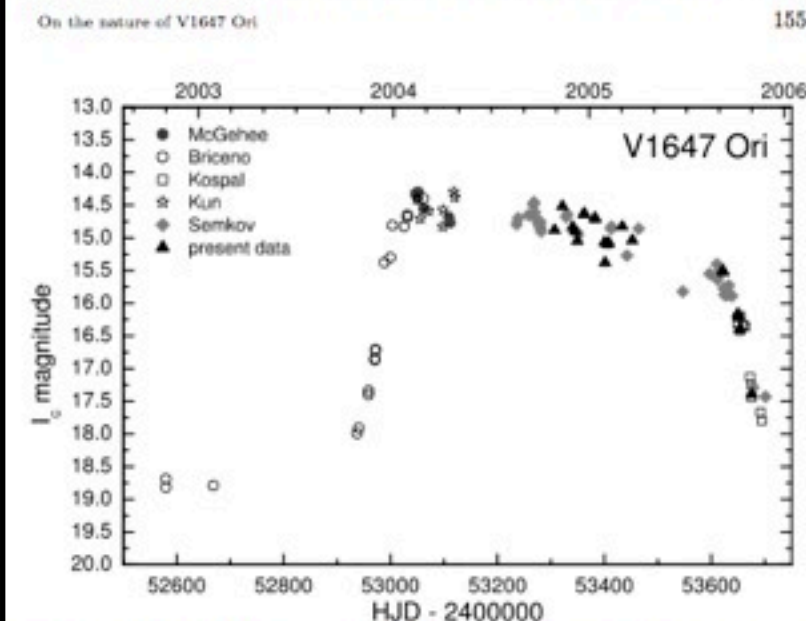


Figure 4. V1647 Ori light curve in the I_C passband. Our data and data from McGehee et al. (2004), Briceño et al. (2004), Kóspál et al. (2005), Kun et al. (2004) and Semkov (2004, 2006) were used.

Characteristics:

- Very rare
- Outbursts repeat with a time scale of 40 years (1978, 2003)
- Amplitude: 5 mag over 4 months
- Outbursts last for 2 years
- Spectra: F or G supergiants
- Spectrum: red, heavily veiled continuum with strong emission of H_α ; in blue consistent with an early B spectrum
- X-ray variability present
- FU Ori and V1057 Cva rise over 1 yr. whereas V1515 Cva rise over 20 years

Triggers:Be

OGLE and MACHO data were studied for Be stars.

- OGLE (LMC, SMC): Sabogal et al. 2005 [g](#), Mennickent et al. 2006 [g](#)
- OGLE (Bulge): Sabogal et al. 2008 [g](#)
- MACHO: Keller et al. 2002 [g](#)

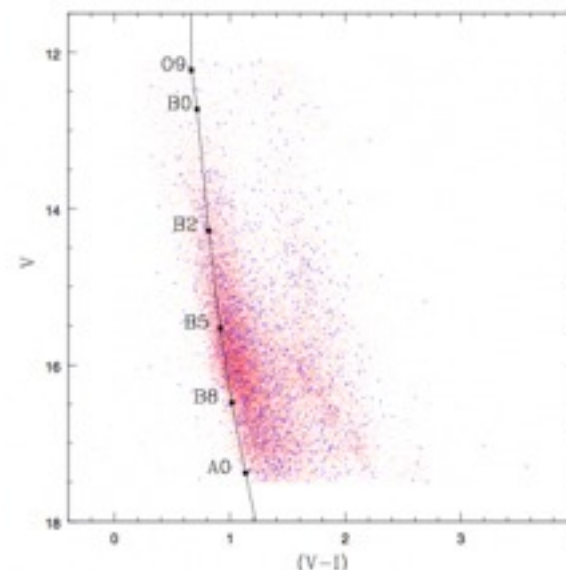


Fig. 4. V vs. $(V - I)$ diagram for the selected Be star candidates. The track of the main sequence (MS) (Allen 2000) is shown for reference. Apparent V magnitudes for it were calculated assuming the distance modulus of the Galactic bulge (14.5 mag) and $A_V = 2.23$ (obtained by calculating the mean of A_V values of the 48 Galactic Bulge fields).

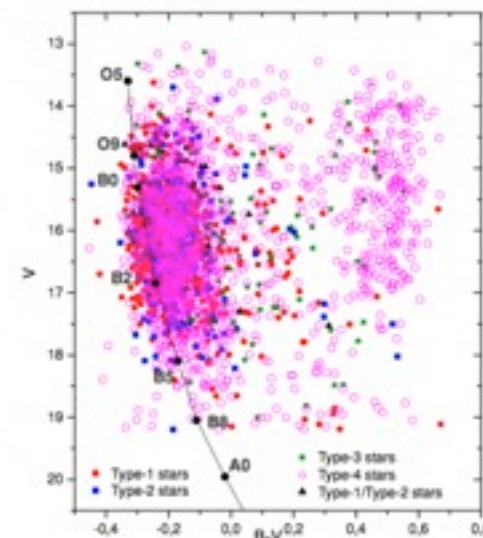


Figure 1. V versus $B - V$ diagram for the total sample of stars of the LMC. The track of the main sequence (Allen 2000) is shown for reference.

Preliminary Advert

SCIENCE FROM GAIA ALERTS

workshop supported by GREAT
(Gaia Research for European Astronomy Training)

Cambridge, 23-25 June 2010

more info soon on Gaia Science Alert WG wiki:
<http://www.ast.cam.ac.uk/research/gsawg/>